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INSTRUMENTATION FOR VEHICLE MOBILITY TESTING IN A TROPICAL ENVI--ETC(U)
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INSTRUMENTATION FOR VEHICLE MOBILITY TESTING IN A TROPICAL ENVIRONMENT

Colorado State University,
Fort Collins, Colorado

June 1966

Contract Report No. 3-154

COLORADO STATE UNIVERSITY

THAILAND TRAFFICABILITY INSTRUMENTATION TEAM

Technical Report

Instrumentation for Vehicle Mobility Testing in a Tropical Environment

under contract with
Department of the Army
Waterways Experiment Station
Vicksburg, Mississippi
and
Advanced Research Projects Agency (OSD)

Contract No. DA-22-079-eng-378 (Negotiated)

S. J. Clark, Assistant Professor
Department of Agricultural Engineering
Campus Coordinator for Project

Colorado State University
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ACKNOWLEDGMENTS

The author wishes to express appreciation to the Advanced Research Projects Agency and the Waterways Experiment Station for the support which permitted this work to be carried out.

The author would also like to take this opportunity to thank John Pope, Harry Leiby and Hillar Ilves for their assistance in preparing this report.

INTRODUCTION

Under the terms of contract No. DA-22-079-eng-378 (Neg.) with the Waterways Experiment Station, Vicksburg, Mississippi, Colorado State University agreed to provide technical assistance to the Advanced Research Project Agency in Thailand. This assistance included:

1. The design of instrumentation and associated systems for research and development testing related to vehicular trafficability
2. Fabrication, installation, operation, and maintenance of the above systems
3. The development of testing procedures
4. The collection, reduction, and compilation of test data
5. The preparation of technical reports
6. The training of local technicians to perform similar tasks

To provide the above assistance Colorado State University provided a three-man instrumentation team which included:

1. John V. Skinner, Instrumentation Engineer
2. Harry B. Leiby, Technician
3. Robert H. Horth, Junior Research Engineer

The University also furnished a campus coordinator and secretary on a part time basis. Richard T. Shen served as the campus coordinator until 1 August 1965 when he accepted an assignment in Brazil. His vacancy was filled by the author of this report.

This contract was initiated 15 August 1963 and terminated 14 August 1965. An outline of the team accomplishments during this period is presented below in sequence:

1963

October	Two members of CSU team arrived in Bangkok and settled in
November	Third CSU team member arrived in Bangkok Drew plans for instrument calibration Made instrumentation for hand penetrometer and bevameter Assisted in radio wave reflection calculation
December	Observed field testing of "Jiger"

1964

January	Designed a low pressure transducer Assisted in installation of engine hour meters on Power Wagon Assisted in preparations of proposed drawbar pull test procedure
February	Started "fifth" wheel universal joint drawings Designed and made shop drawings of platform scales Tested the low pressure transducer
March	Finished "fifth" wheel universal joint drawings Fabricated base of platform scales Completed calibration unit for hand bevameter and penetrometer Attempted unsuccessfully to regulate voltage on gasoline generator Tested a DC-AC converter Designed brass weights for calibrations Calibrated bevameter force transducer Tested tension and shear in three wood specimens and their kinetic energy absorbtion Designed wood armor test section forms Designed clevices for SEATO tension-compression machine for large force transducer calibration
April	Designed driver simulation platform Designed orthogonal accelerometer mountings Designed mountings for accelerometers on "vehicles suspension, axle, etc." Designed aluminum gasoline tank with a fuel level indicator Completed calibration and recording system for driver simulation platform Completed bevameter torque and displacement transducers and calibrated platform scales
May	Completed calibration of bevameter torque and displacement transducers Completed instrumentation of Power Wagon Assisted in fuel consumption and vibration tests at Hua Hin Instrumented Hover Truck for drawbar Aided Program Manager in Surveillance on redesign of electronic intrusion alarm system

June	Fabricated and calibrated a graduated fuel container Took accelerometer and fuel flow data for Power Wagon and reduced the data Participated in soil tests Designed and fabricated a calibration box Finished and calibrated three dynamometers Designed and fabricated Power Wagon wheel revolution counters Assisted Surveillance on electronic intrusion alarm system Obtained data on Hover Truck: fuel consumption, acceleration, drawbar pull, wheel slip, and soil strength
July	Comparison tests of Hover Truck and Land Rover: drawbar pull, vibration, gas consumption, and soil tests Reduced this data Repaired and calibrated two soil moisture meters Designed wheel cams for Power Wagon and 3/4 ton truck Experimented with an instrumented roll and pitch measuring system
August	Completed Power Wagon and 3/4 ton truck instrumentation Conducted drawbar pull tests on the above Designed rolling resistance measurement brackets for Spryte Completed a six channel calibrator unit for transducers Repaired and recalibrated a flow meter
September	Conducted Power Wagon tests: fuel, vertical and lateral acceleration, wheel slip, and drawbar pull Fuel consumption measurements for RAC Designed Spryte bracketry (several items) Modified and calibrated a temperature sensing device Prepared a resume of Team's capabilities for M.R.D.C.
October	Redesigned Spryte trackslip brackets Redesigned aluminum truss Rewired fuel flowmeter Fabricated a small calibrated fuel tube Assisted in Power Wagon tests Assisted as test photographer Modified and calibrated an air speed and direction indicator
November	Completed fuel, bollard-pull, track slip tests on Spryte Measured cushion pressure on Hover Truck Installed instrumentation on Hover Truck for drawbar pull and trafficability tests Modified six intrusion detectors Repaired three soil moisture meters and one lab balance Submitted an electro-osmosis proposal Modified drawbar pull field control units Designed a drawbar pull data reduction monogram
December	Ran drawbar pull and rolling resistance tests on Hover Truck while varying air pressure Reduced above data Measured vibration of vehicle and driver on Power Wagon Started to construct a photo evaluator

<u>1965</u>

January	Reduced vibration data Repaired a shearmeter and penetrometer Fabricated new central control unit Submitted electro-osmosis proposal to ARPA Designed an instrumented vegetation bumper Repaired six soil moisture meters
February	Completely built two 15½ lb. transducers Disassembled Hover Truck Performed drop test on front axle of Power Wagon Built a shaker table
March	Studied simplification of developing recordings in field Built portable continuous developer Adapted penetrometer and shearmeter to CSU equipment, tested and demonstrated it to MRDC Measured soil strength for anticipated XM-561 tests Preliminary tests on vegetation bumper Built instrumentation platform
April	Field testing of vegetation bumper and developing test Trained Thai engineer in field operations Rolligon drawbar pull and rolling resistance tests Built low air pressure meter Assisted in gun barrel temperature measurements Modified vibration table Completed and tested M-116 wheel cams
May	Modified vegetation bumper for vertical force Rolligon drawbar pull and rolling resistance tests and soil tests Gun barrel temperature experiments conducted Experiment with WES in soil measurement repeatability Designed sled for soil meters Built additional drawbar pull transducers Modified wheel cams CSU engineering assistant returned to USA
June	Prepared for XM-561 field tests Modified calibration boxes Put shelf in Land Rover Fabricated brackets for XM-561: accelerometers (6), steering torque transducer, pitch and roll cams for wheel slip, and also fuel consumption piping. Fabricated same bracketry for 3/4 ton truck Assisted in XM-561 drawbar pull and rice paddy tests Experimented with direct readout of soil measurements
July	Completed pack frame fatigue tests Soil tests at Bangpu Completed XM-571 track slip cam hardware Built three transducers for vegetation bumper Replacement for CSU junior research engineer arrived in Bangkok and CSU instrumentation engineer returned to USA

August   Provided vegetation test instrumentation
Calibrated three transducers
Studied optimizing force transducers
Completed M-116 instrumentation
Tested M-116 drawbar pull, rolling resistance and trafficability
Built six fuel consumption tubes
XM-571 articulation joint instrumentation

The above outline of accomplishments shows that the instrumentation team performed a rather wide range of tasks. The major portion of the work load, however, was connected with vehicle testing. For this reason only the details of tasks involving the design and operation of instrumentation systems for research and development related to vehicular trafficability will be reported herin.

During the contract period the Colorado State University Thailand Trafficability Instrumentation Team instrumented and assisted with trafficability tests of the following vehicles:

1. Dodge Power Wagon
2. Vickers Hover Truck
3. M 37 3/4 ton truck
4. Spryte
5. XM-561
6. Rolligon
7. M-116
8. XM-571

Test pictures of these vehicles are shown in Figures 1 through 8.

Figure 1. Dodge Power Wagon Equipped with Terra Tires

Figure 2. Vickers Hover Craft

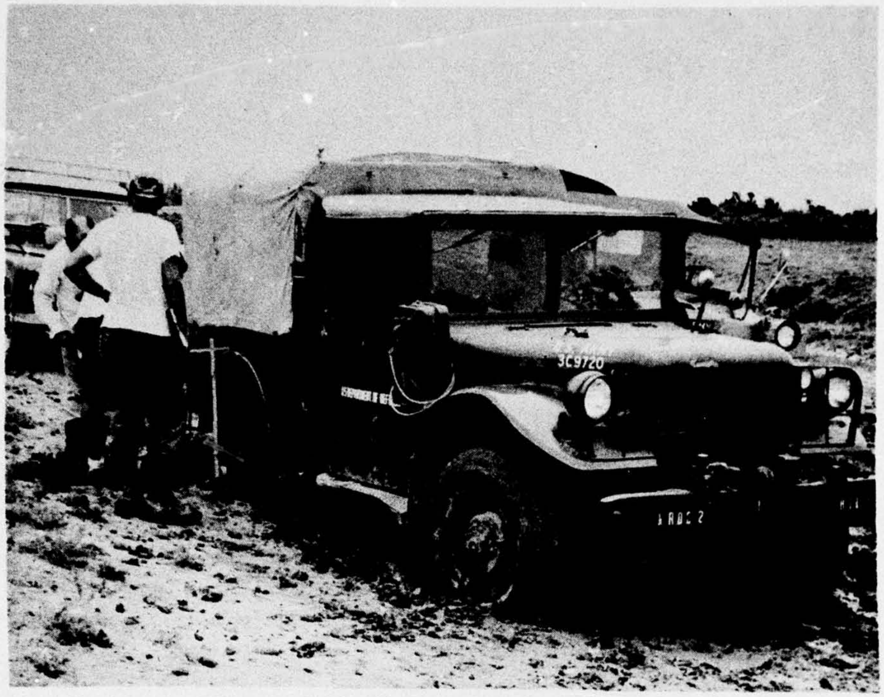


Figure 3. M 37 3/4 Ton Truck

Figure 4. Spryte

Figure 5. XM 561

Figure 6. Rolligon

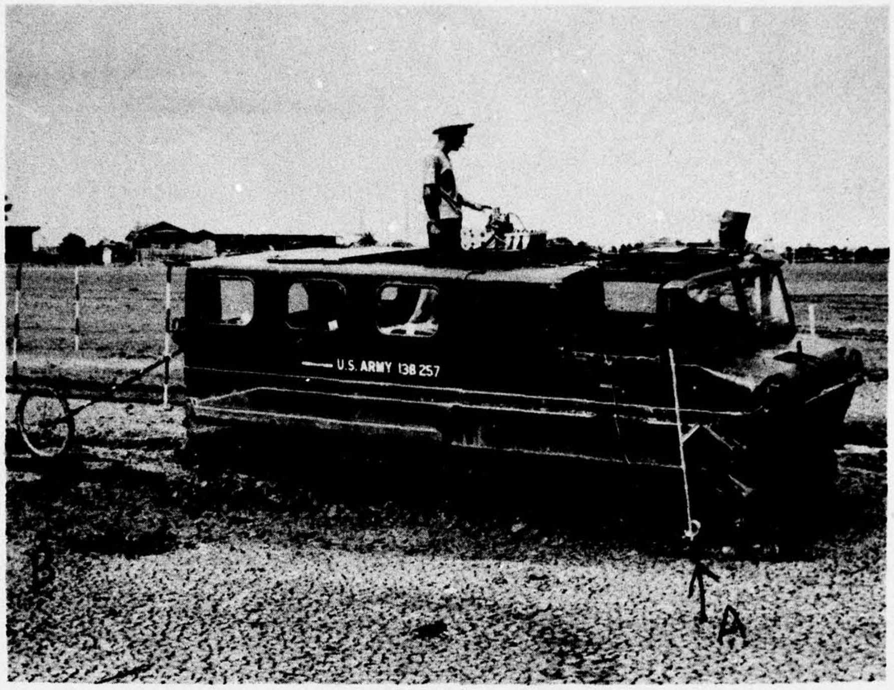


Figure 7. M-116

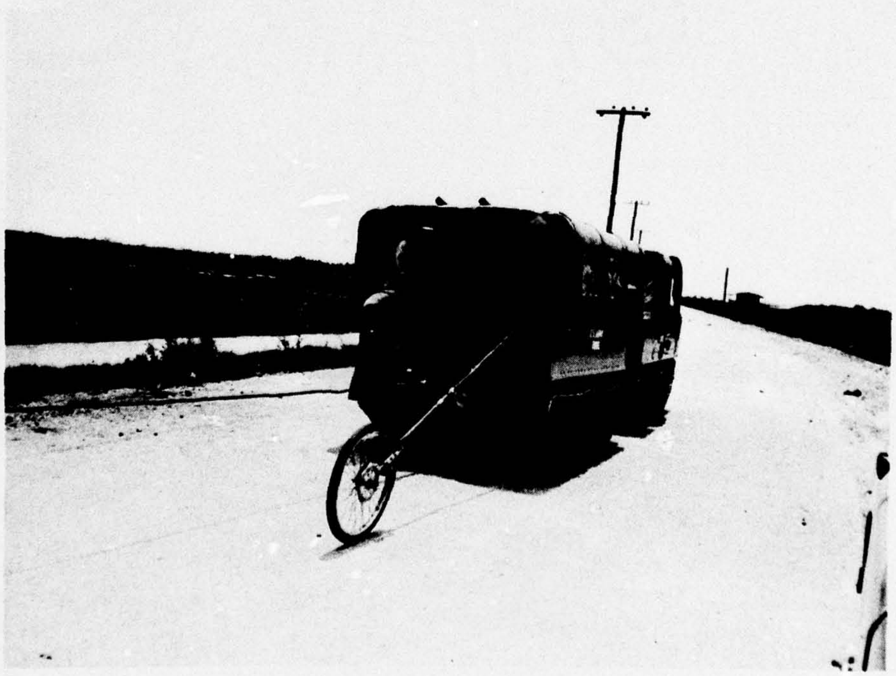


Figure 8. XM-571 Articulated Vehicle

INSTRUMENTATION AND MEASUREMENT SYSTEMS FOR VEHICLE TESTING

Introduction

Instrumentation and associated bracketry was designed for making the following measurements:

1. Fuel consumption
2. Drawbar pull, bollard pull and rolling resistance
3. Track and wheel slip
4. Vehicle roll, pitch and yaw
5. Vehicle and operator acceleration
6. Vegetation impedance

Some special problems were encountered in recording the output from transducers for making the above measurements. These problems will be discussed in a special section on recording systems.

Fuel Consumption

Early fuel consumption tests were measured using standard flow meters. The unreliability of these meters was a constant source of trouble. As a result the system shown in Figure 9 was used in later tests. The system was nothing more than a fuel container with a graduated cylinder to indicate the fuel level. This system provided a simple reliable method for determining average fuel consumption.

Figure 9. Calibrated Fuel Can Installed on Dodge Power Wagon

Drawbar Pull, Bollard Pull and Rolling Resistance

Drawbar pull tests for the test vehicles were performed as indicated in Figure 10. The load for the test vehicle was supplied by towed vehicles. The tow cable was connected to the test vehicle through two tension load cells. The signal from one of the load cells was recorded by an oscillograph. The second load cell was included so that the drawbar pull magnitude could be observed on a meter in the test vehicle.

The force exerted by a floating vehicle anchored to a stationary point by a cable is known as bollard pull. The standard load cells were connected between the tow cable and the stationary point to measure the force.

Rolling resistance tests were performed as indicated in Figure 11. The load cells were used in the same manner described above.

The general design of the tension load cells used is shown in Figure 13. A tubular construction was used as shown in Figure 12. This construction was used since the cross sectional area where the strain gages were attached (see Figure 13) could be greatly reduced without too much loss of lateral rigidity. The dimensions of the machined sections were adjusted as shown in Figure 12 so that the axial stress at the rated loads was approximately constant for all of the load cells. This in turn provided an approximately constant output voltage from all the cells at their rated loads (providing the same type of strain gages were used).

Figure 10. Drawbar Pull Test on the XM-561

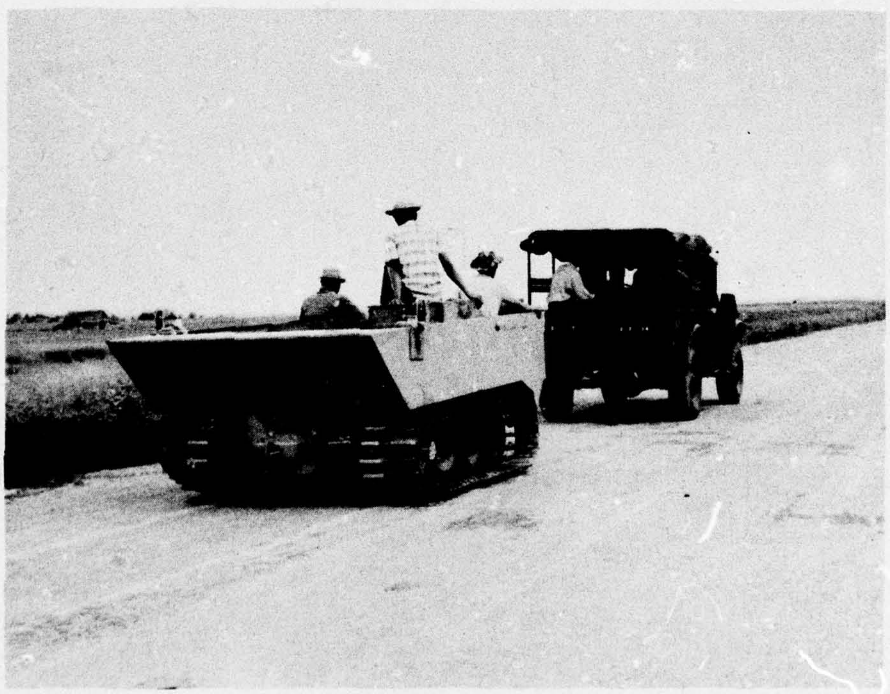
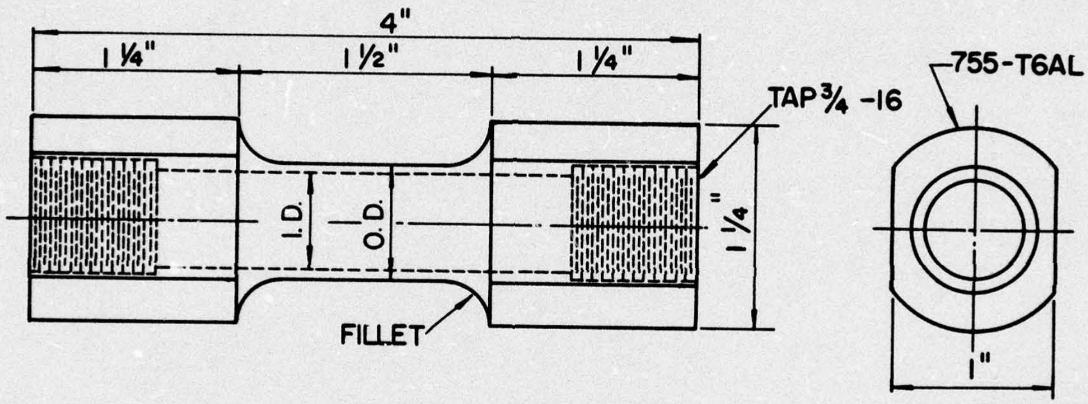


Figure 11. Rolling Resistance Test on the Spryte

P.U. RATING	I. D.	O. D.	WALL THICKNESS	FILLET
500 #	$0.500^{-0.001}_{+0}$	$0.524^{-0}_{+0.001}$	0.012"	$\frac{3}{8}$" R
1000 #	$0.625^{-0.001}_{+0}$	$0.663^{-0}_{+0.001}$	0.019"	$\frac{3}{8}$" R
2500 #	$0.625^{-0.001}_{+0}$	$0.716^{-0}_{+0.001}$	0.0455"	$\frac{1}{4}$" R
5000 #	$0.625^{-0.001}_{+0}$	$0.797^{-0}_{+0.001}$	0.086"	$\frac{1}{4}$" R
10000 #	$0.625^{-0.001}_{+0}$	$0.938^{-0}_{+0.001}$	0.1565"	$\frac{3}{16}$" R



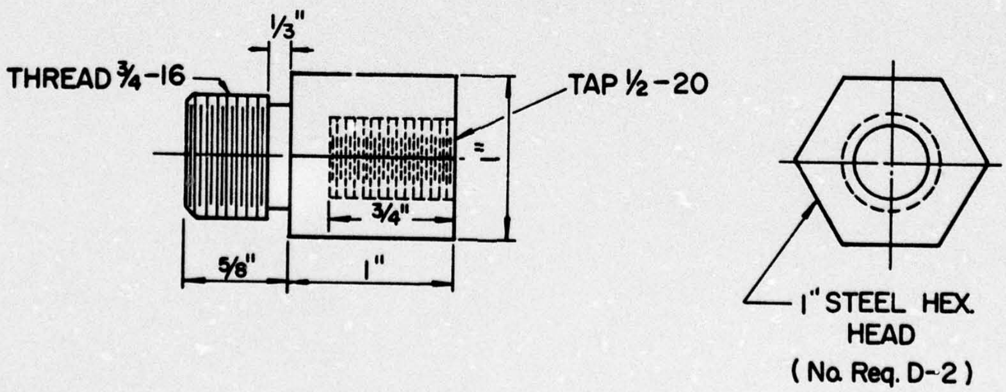


Figure 12. Detailed Drawing of Tension Load Cells

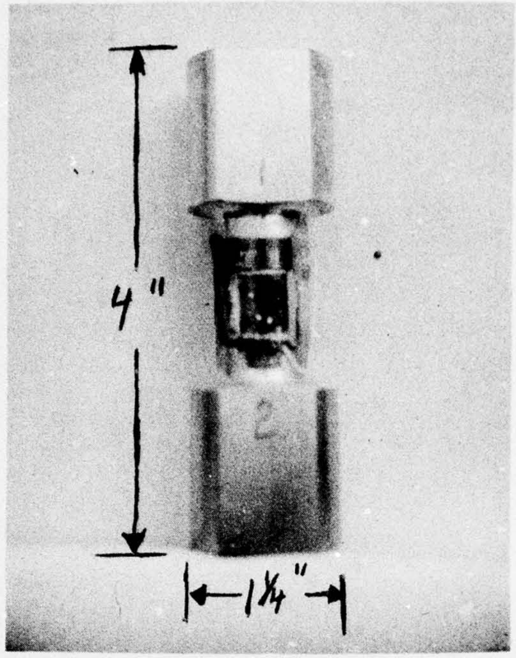


Figure 13. Strain Gage Tension Load Cell Used for Measuring Drawbar Pull, Bollard Pull, and Rolling Resistance

The tension load cells were calibrated at the SEATO Graduate School Materials Testing Laboratory. The hydraulic testing machine shown in Figure 14 was used.

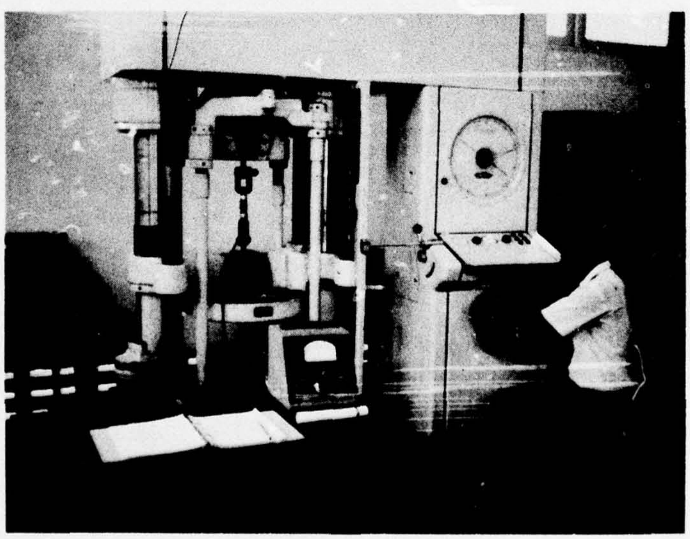


Figure 14. Calibration of the Tension Load Cells at SEATO Graduate School

Track and Wheel Slip Measurements

Track and wheel slip values were obtained from the equation:

$$i = \frac{V_t - V_v}{V_t}$$

where

V_v = actual vehicle speed

V_t = peripheral speed of the traction device contact surface (often termed theroretical vehicle speed).

A fifth wheel was used to obtain the actual vehicle speed. Voltage pulses from a cam-actuated micro switch were recorded (four per wheel revolution) on the oscillograph. A time base was also recorded so that the fifth wheel revolutions could be converted into terms of vehicle speed by a conversion factor.

The peripheral speed of the traction devices was obtained in the same manner. Figures 15 through 17 show the cam micro switch unit bracketry for several of the vehicles which were tested.

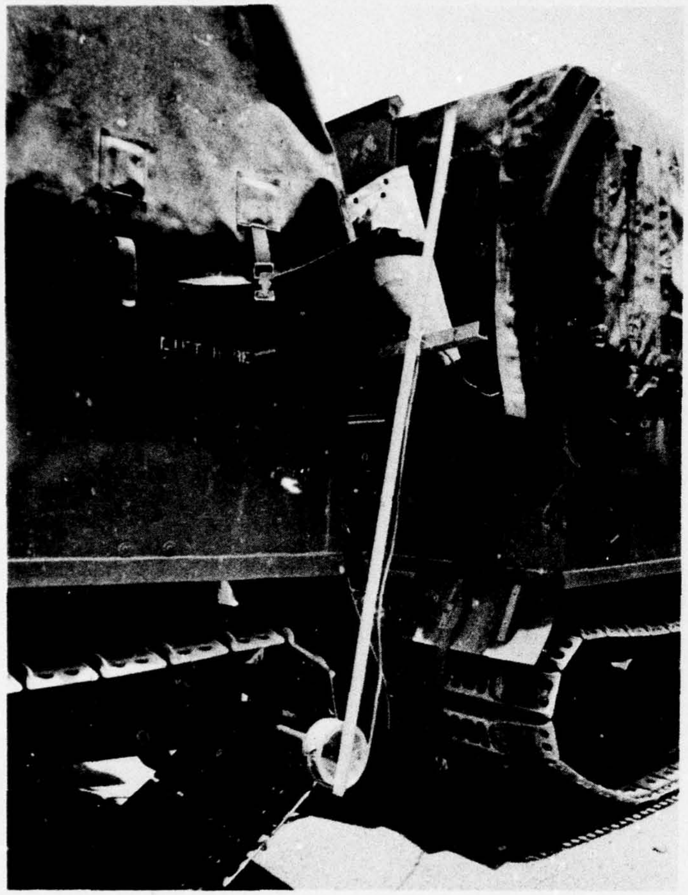


Figure 15. Sprocket Rotation Measurement Device and Bracketry on the XM-571

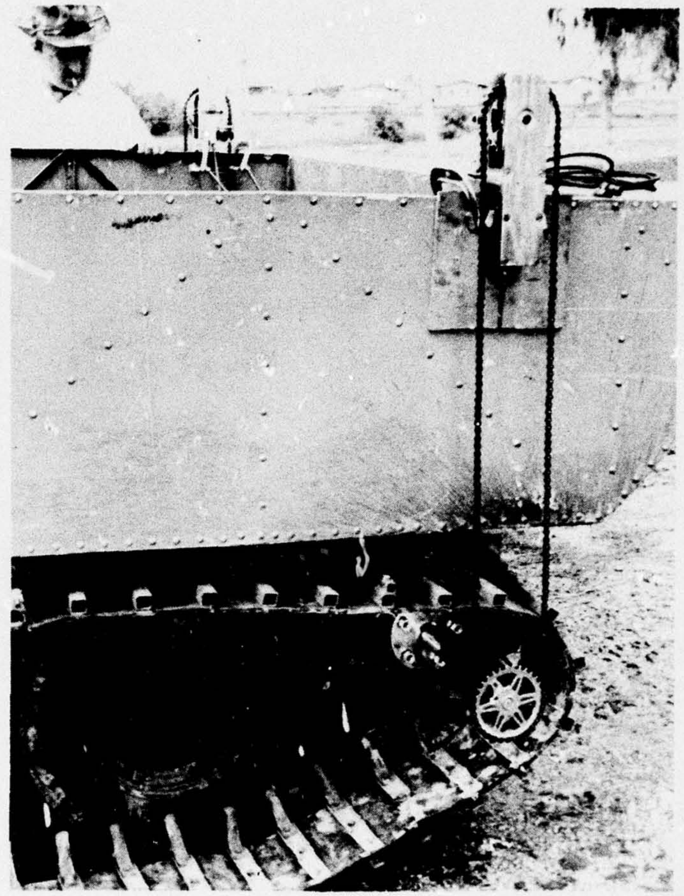


Figure 16. Sprocket Rotation Measurement Device and Bracketry on the Spryte

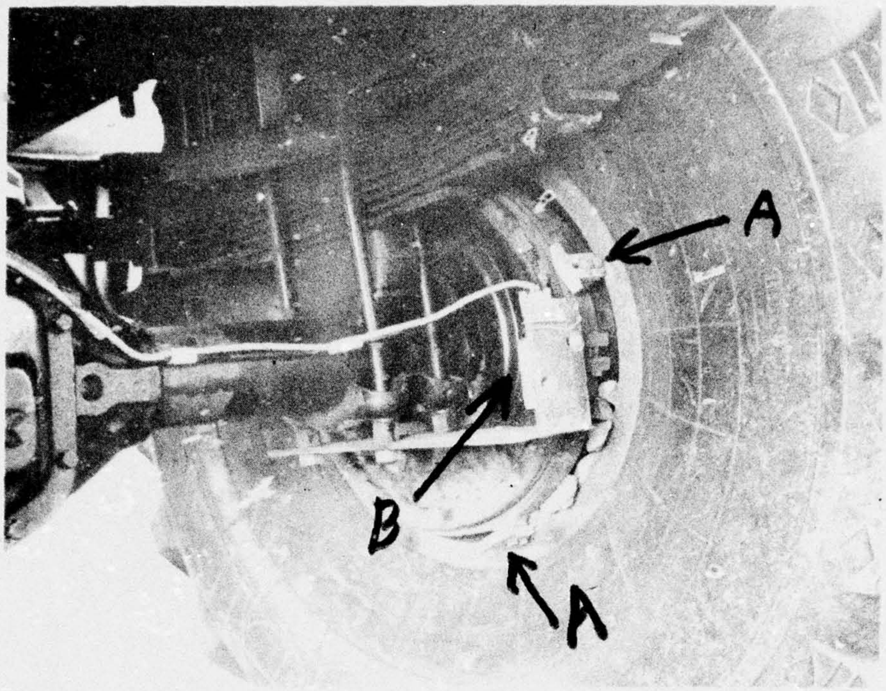


Figure 17. Cam and Micro Switch Installation on the Dodge Power Wagon (A - Actuating Cams; B - Micro Switch Installation)

The special chain driven cam and micro switch unit used on the Spryte (Figure 16) was designed to eliminate problems associated with mud buildup in the standard unit used (Figure 15). The design proved successful.

Vehicle Roll, Pitch, and Yaw Measurements

On articulated vehicles such as the XM-571 it is of interest to know the relative position of the units as it traverses various terrains. The three degrees of freedom (roll, pitch and yaw) were measured by means of precision potentrometers. The potentrometer bracketry for the three measurements are shown in Figures 18, 19, and 20.

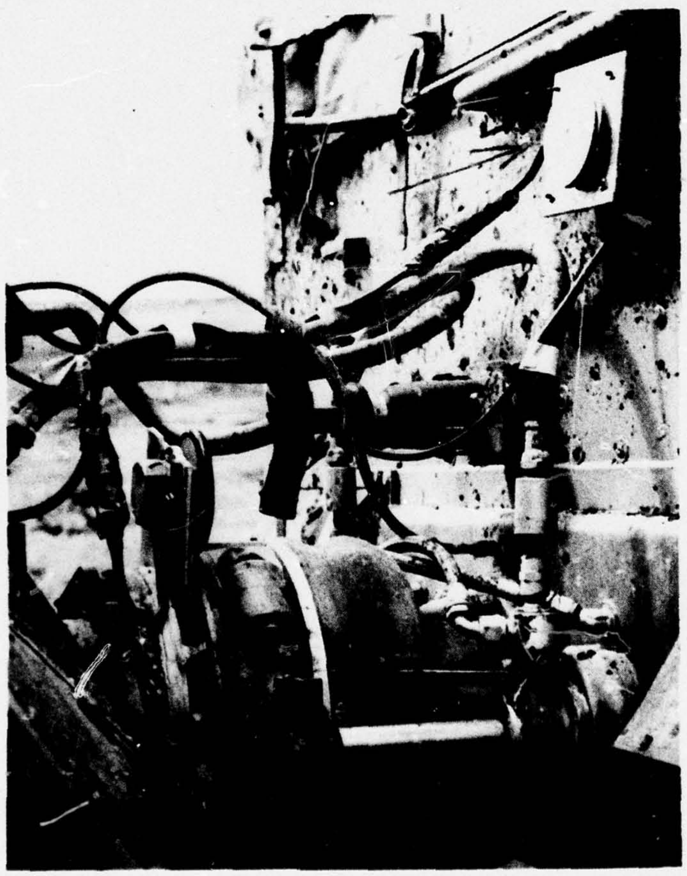


Figure 18. Yaw Angle Measurement Unit Between the Front and Rear Units of the XM-571 (Upper Right Hand Corner)

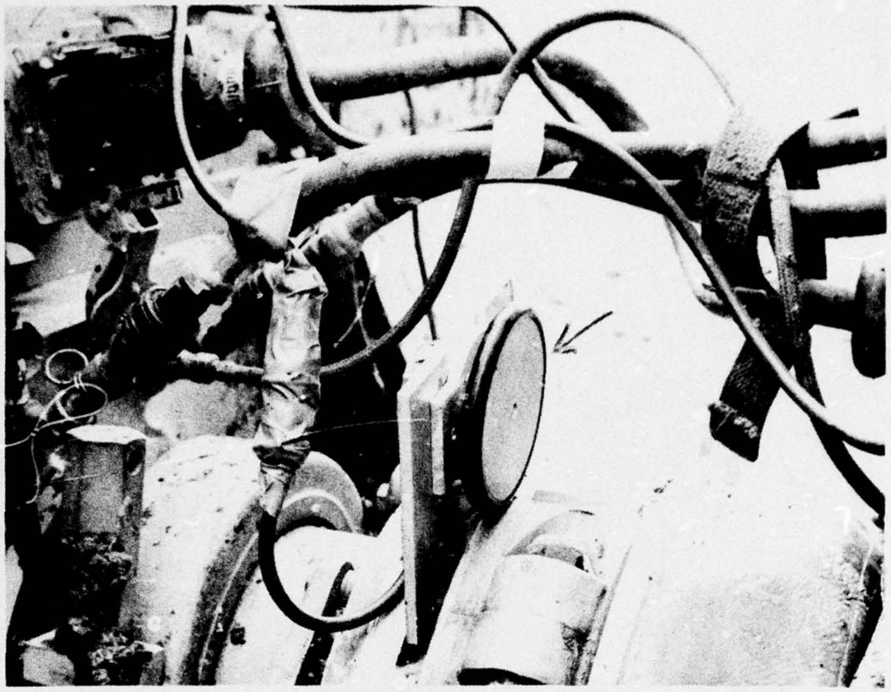


Figure 19. Roll Measurement Unit Between the Front and Rear Units of the XM-571

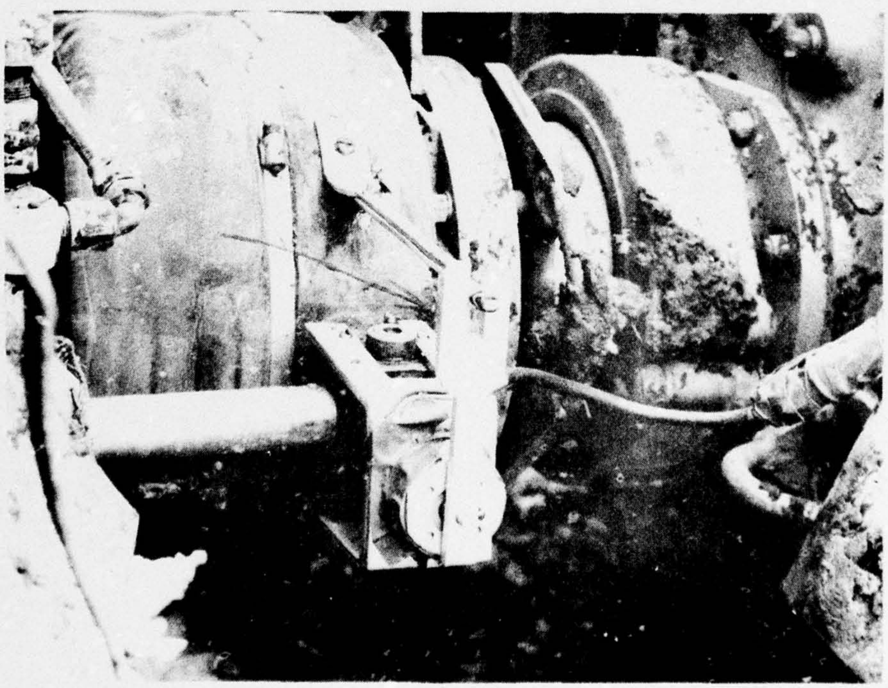


Figure 20. Pitch Measurement Unit Between the Front and Rear Units of the XM-571

Vehicle and Operator Acceleration Measurement

Acceleration measurements were made at various points on several of the vehicles tested. Acceleration measurements on vehicle operators (at the driver's waist) were also made. Standard accelerometers were used so the main instrumentation problem connected with these measurements involved the design and construction of bracketry for mounting the accelerometers.

A special belt shown in Figure 21 was designed to monitor vertical and lateral accelerations at the waist of the vehicle operator.

Acceleration was recorded at randomly selected times as well as points where the ride was roughest. This was done to obtain information regarding the complete vibration spectrum as well as the maximum vibration level.

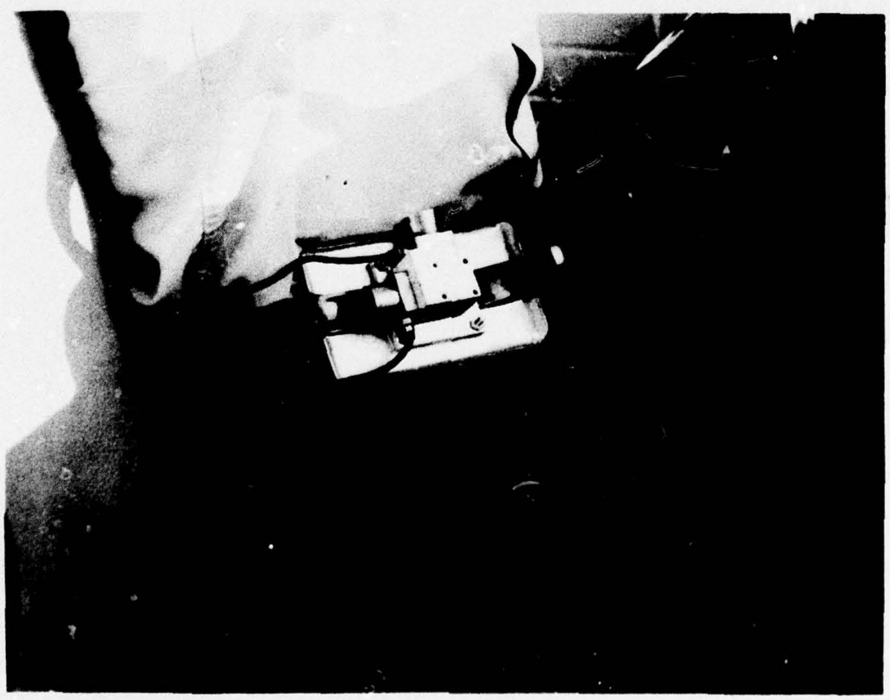


Figure 21. Belt for Monitoring Vertical and Lateral Accelerations at the Vehicle Operator's Waist

Vegetation Impedance Measurements

A vegetation bumper was designed to measure vegetation resistance to vehicle motion. The bumper was mounted on the blade of an Allis Chalmers TL 14 as shown in Figure 22 and 23.

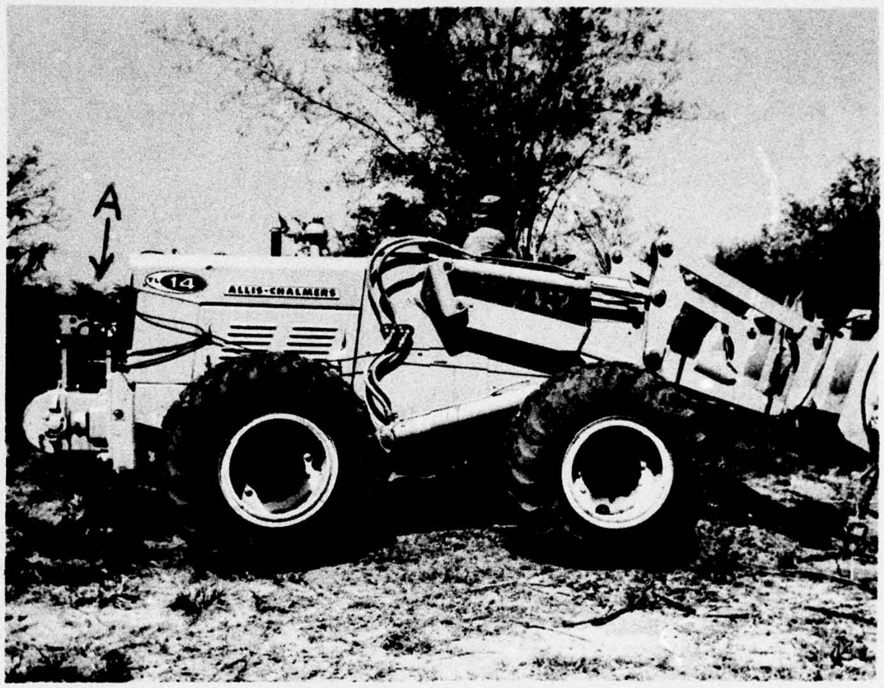


Figure 22. Vegetation Bumper Installation on an Allis Chalmers TL 14 Tractor (A - Recorder System; B - Vegetation Bumper)

The scraper blade could be raised and lowered so that vegetation impedance could be measured from ground level up to a height of six feet.

The horizontal load on the vegetation bumper was resisted by two compression transducers (rated load = 15,000 pounds each). Early tests indicated that both the vertical components of force on the vegetation bumper was also significant in determining the vegetation impedance due to deflection of the vegetation as it passed under the bar (see Figure 23).

Figure 23. Small Tree Being Deflected by Vegetation Bumper (A - Horizontal Force Transducer)

The vertical member of the vegetation bumper frame was instrumented to measure the vertical forces on the bumper as indicated in Figure 24.

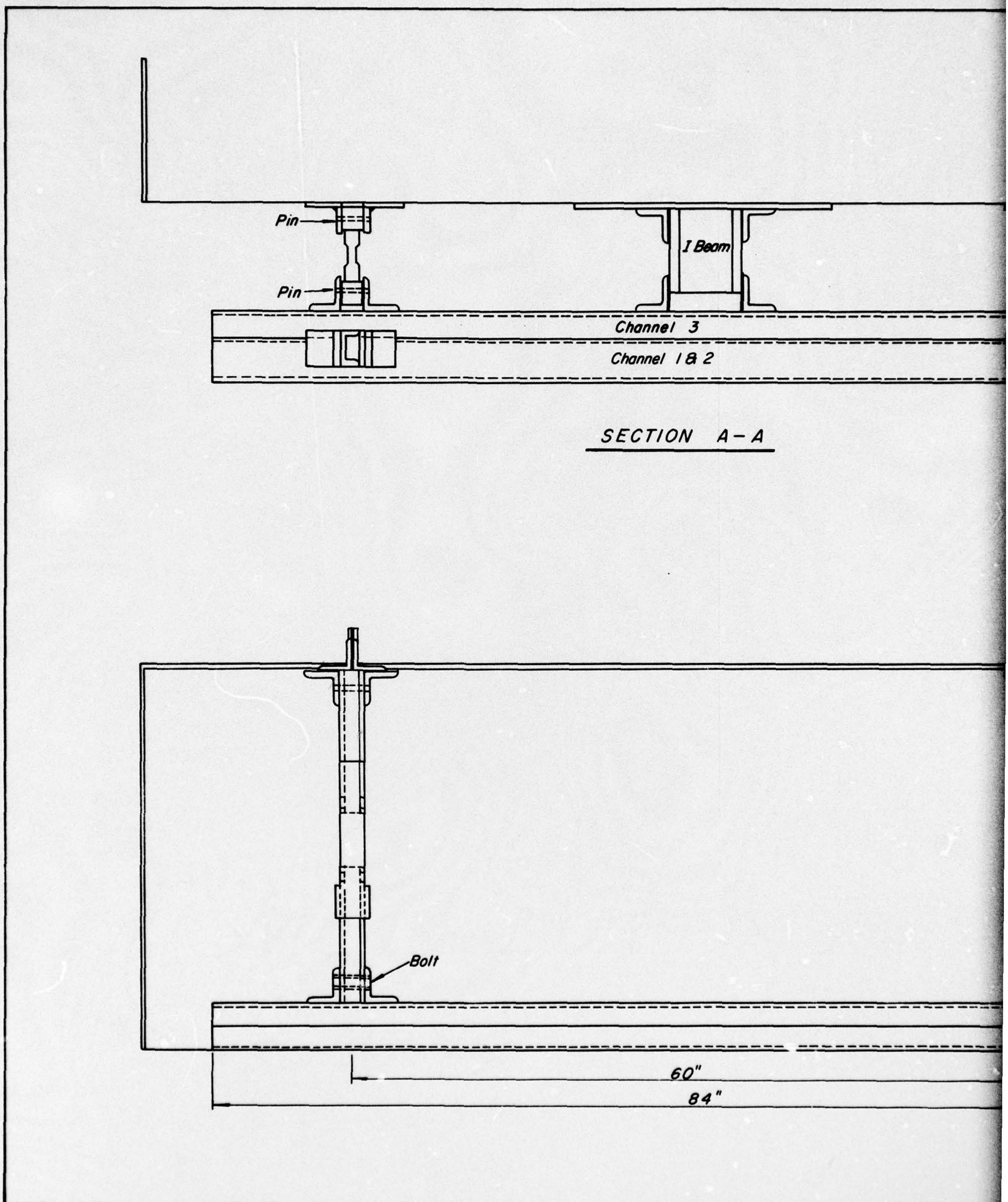
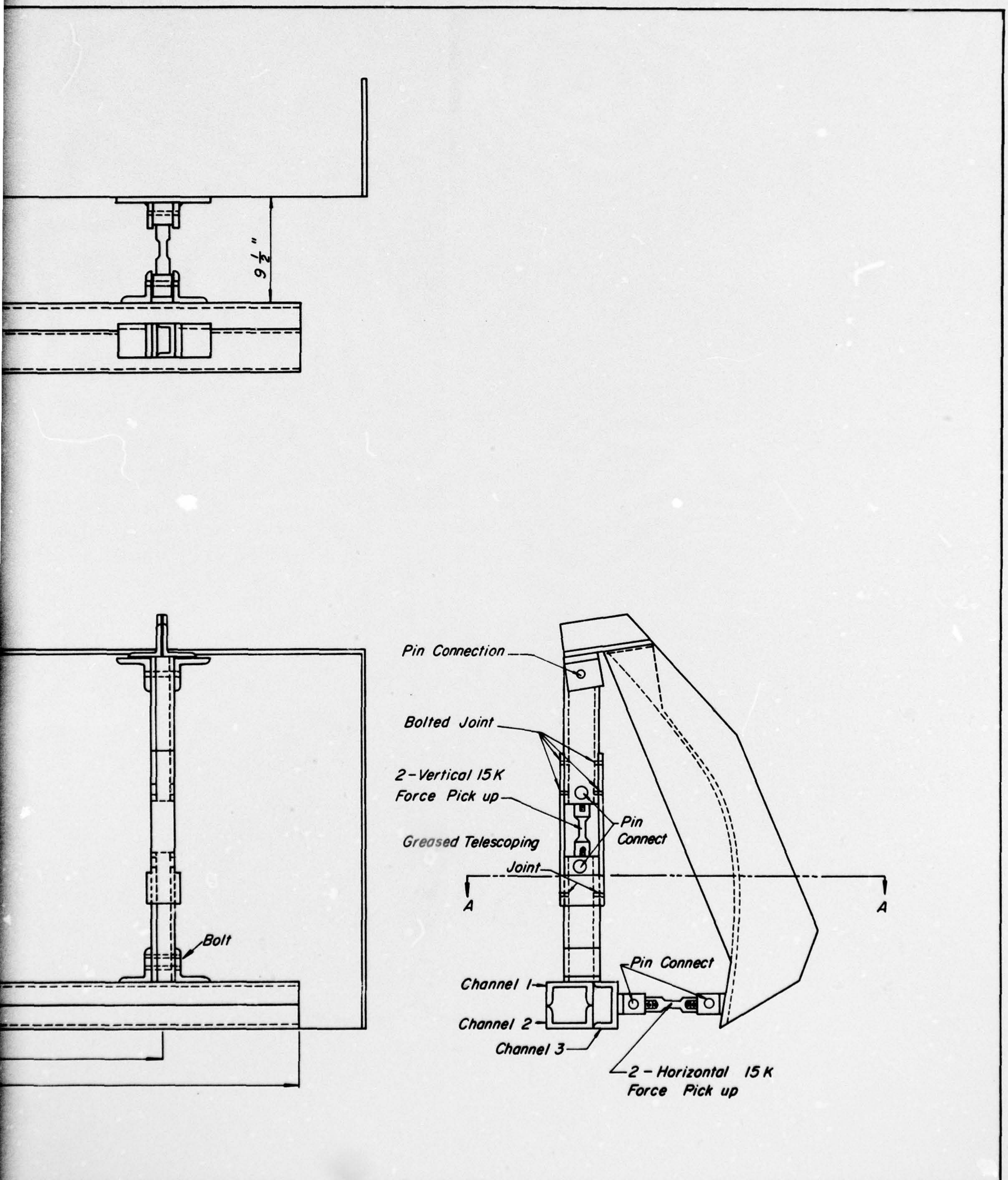


Figure 24. Vegetable Bumper Frame Design for Me



ign for Measuring Vertical and Horizontal Forces

RECORDING AND CALIBRATION SYSTEM

Recording System

The recording system was designed and fabricated by H. B. Leiby. It includes a 12-channel, light beam, oscillograph; a bridge balance-calibration unit; and a battery pack. The battery pack (six 6V No. 918 lantern batteries) provides d.c. power for transducer excitation. A separate battery pack consisting of two 12 volt automotive batteries is used for driving the oscillograph when 24 volt power is not available on the test vehicle.

The recording system was mounted on a common base as shown in Figure 25. The scale at the bottom of the photograph shows that the system is quite small considering its six-channel capability. Its small physical size coupled with the use of d.c. (battery) power makes this an ideal recording system for vehicle mobility testing in remote areas for the following reasons:

1. The system can almost always be carried on the test vehicle, thus eliminating the need for an instrument vehicle.
2. The use of battery power eliminates the need for an a.c. power supply. The use of an engine-driven power supply would require additional space and be an additional source of trouble.

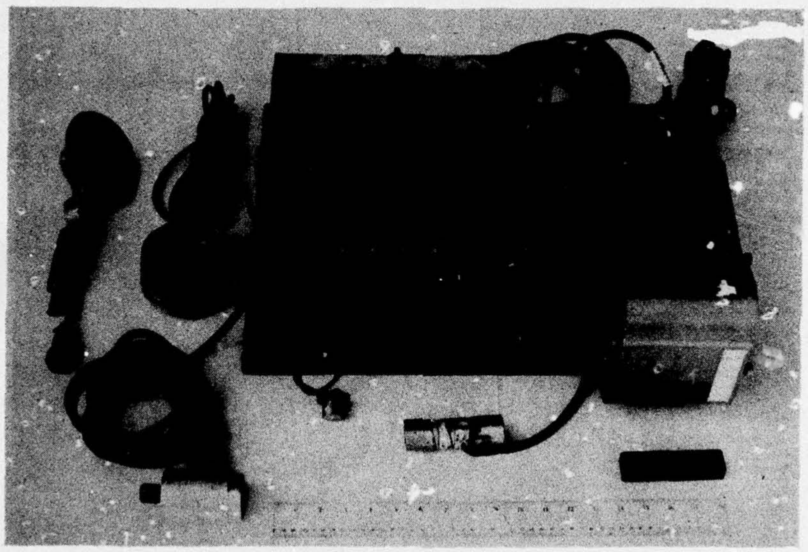


Figure 25. The CSU Recording System Connected to a Variety of Transducers

Recording Oscillograph

The outputs from the transducers were recorded by a Century Model 409-X, twelve-channel oscillograph. This unit proved ideal for field testing. It is an extremely rugged instrument and requires a minimum amount of maintenance even in a tropical environment such as Thailand. This oscillograph incorporates the use of light beam galvanometers for recording. The chart paper must therefore be developed. The developing is normally performed in a laboratory developer such as the Viewlex Model A Oscillomatic. It was found, however, that field developing was necessary to allow quick detection of mechanical or electrical failures in the data gathering systems. The direct print conversion unit for the Century 409-X Oscillograph was not suited for the Thailand environment according to the manufacturer. Kodak photosensitive paper proved unsuitable because the radiation emitted by the galvanometers was not sufficiently intense in the ultraviolet range to affect the paper.

A field developer was therefore assembled by the CSU Instrumentation Team. The tank and roller system from a Viewlex Oscillomatic developer was installed in a light weight frame. The rollers were driven by hand cranks to eliminate the need for an a.c. power unit. The developing solutions used in the laboratory were used in the field developer. The developed recording paper was air dried. The field developer proved successful. It was light enough to be carried by one man and was capable of developing chart paper at a rate of six inches per second.

Bridge Balance-Calibration Unit

The bridge balance-calibration unit was designed as a companion instrument to the Century Oscillograph. It provides a simple and accurate method for balancing and calibrating bridge circuits from resistance-type transducers. Potentiometer transducers and switching circuits can also be powered and monitored through the bridge balance-calibration unit. This is accomplished through use of external resistor networks located within the Amphenal input plug from the potentiometer or switch.

Front and rear views of the unit are shown in Figures 26 and 27. The enclosure is standard unit. The hole layout for the potentiometers and switches is shown in Figure 28.

The wiring diagram for the bridge balance-calibration unit is shown in Figure 29. From the wiring diagram it can be noted that any one of the seven precision resistors can be placed in parallel with bridge legs AB or AC on any channel by means of the channel selector switch S-1, the directional switch S-2, and the calibrate switch S-3. Placing a resistor in parallel with a bridge leg provides an equivalent strain when the bridge resistors are SR-4 strain gages. The equivalent strain method provides a very convenient method of calibration which is described in the next section.

A list of materials for the bridge balance-calibration unit is as follows:

Quantity	Description
1	aluminum box, 2"x7"x11"
6	plug amphenol (4 wire), AN-310-1452S
1	plug amphenol G1-1 (14 wire), AN-3106-20-27S

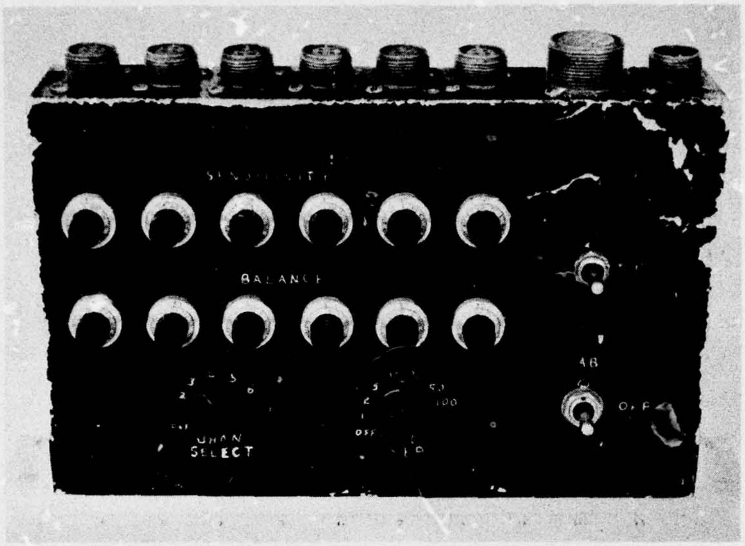


Figure 26. Front View of Bridge Balance-Calibration Unit

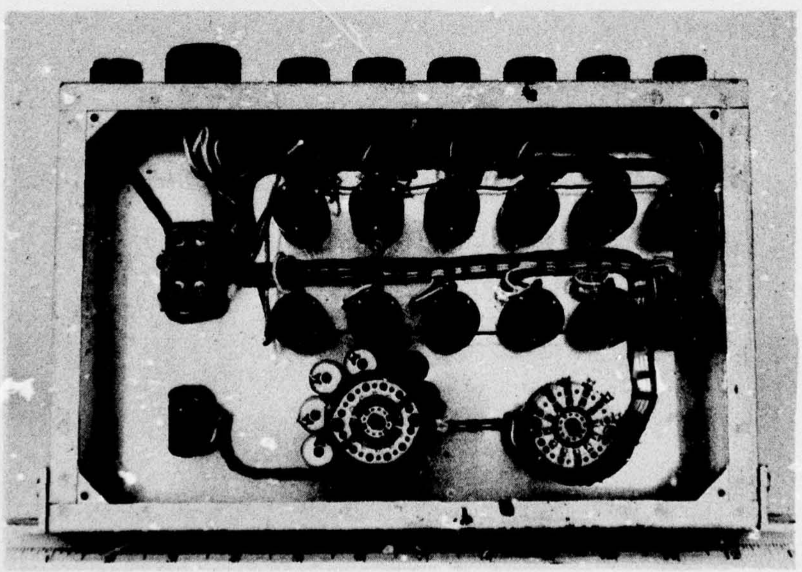


Figure 27. Rear View of Bridge Balance-Calibration Unit

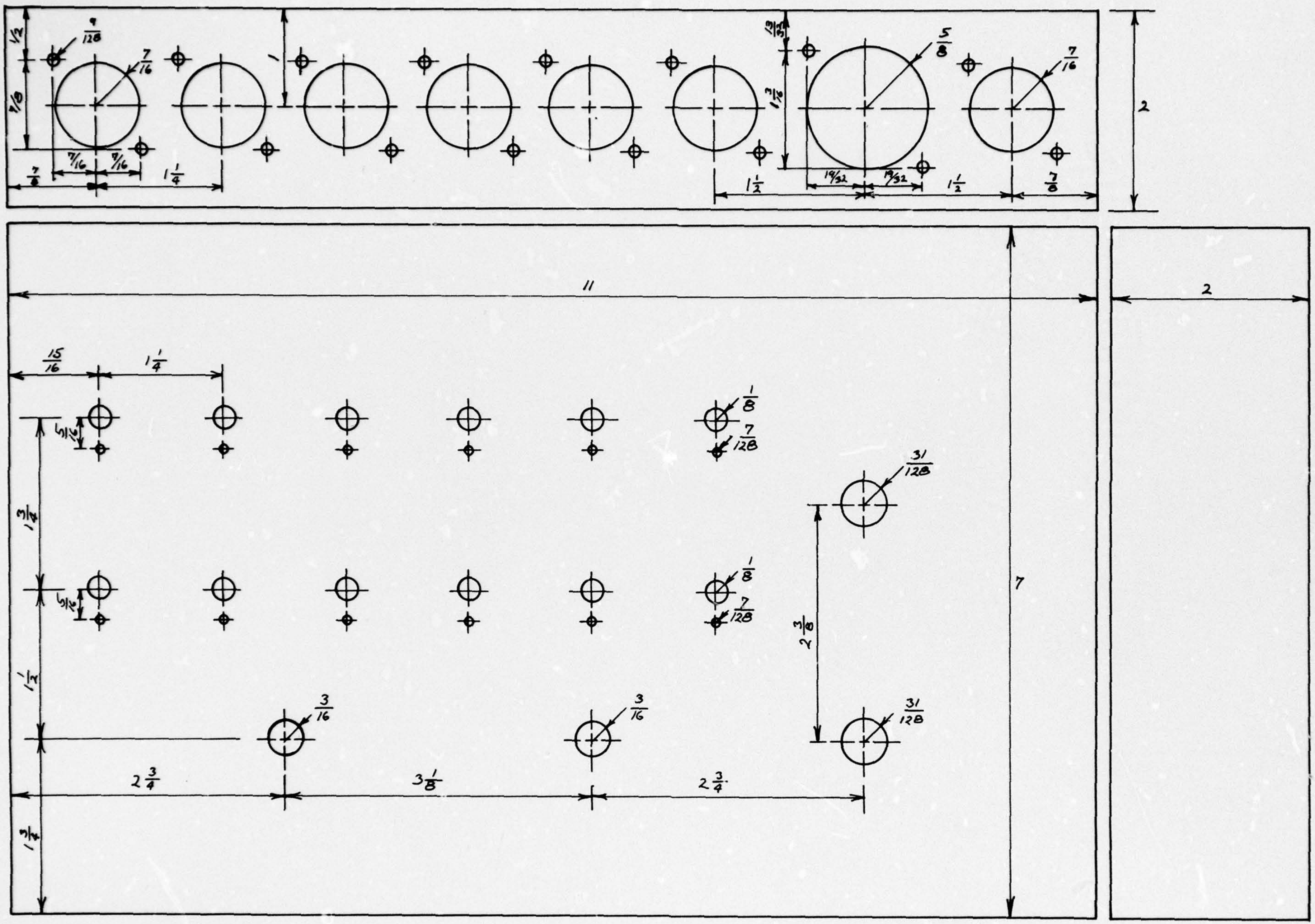


Figure 28. Bridge Balance-Calibration Unit Enclosure with Hole Layout for Hardware

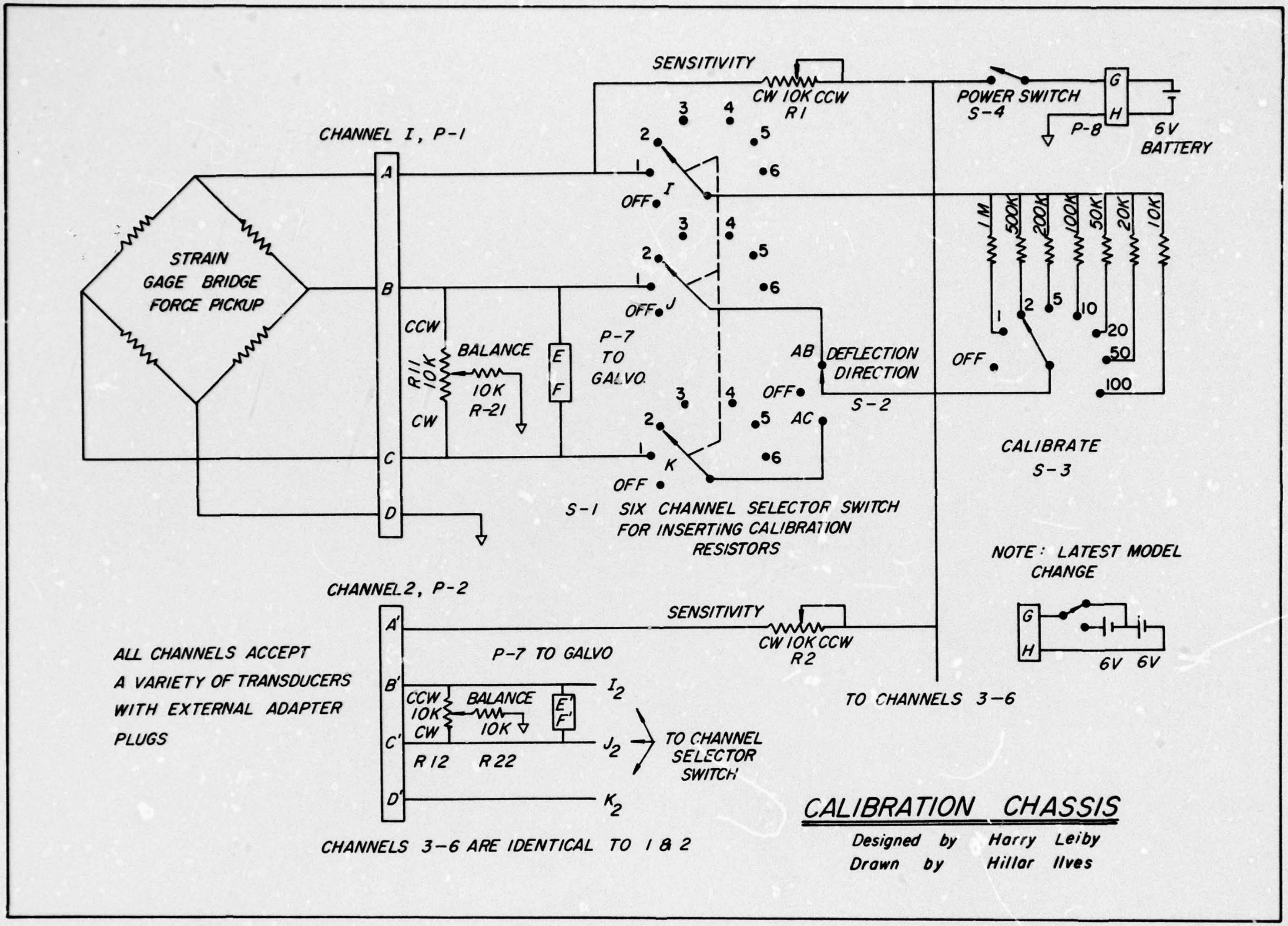


Figure 29. Bridge Balance-Calibration Unit Wiring Diagram

Quantity	Description (continued)
12	No. 7221, 10k $\pm$ 3%, Helipot, Beckman Industries, Fullerton, California
1	2 pole, 12 position switch
1	3 pole, 12 position switch
1	DPDT switch
1	SPDT switch
1	plug amphenol 14S-2P (4 wire). AN-3106-14S-2P
7	resistors $\pm$ .1%, 10k, 20k, 50k, 100k, 200k, 500k, 1m

The use of external networks installed in the Amphenal connecting plugs from potentiometers and switching transducers has been mentioned previously. These networks are shown in Figures 30 and 31. The resistor R_1 in the switching external network is selected to limit the galvonometer current; the balance potentiometer is used to set the desired galvanometer deflection. The resistor R_1 in the potentiometer external circuit is also selected to limit the galvanometer current. The variable resistor R_2 is a course gain control; fine gain adjustment is controlled by the gain potentiometer in the bridge balance-calibration unit. Proper damping resistors must be selected and inserted between pins B and C on both of the above networks.

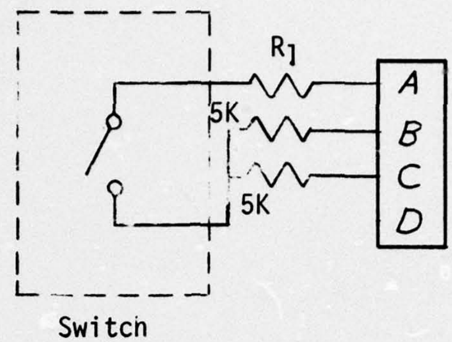


Figure 30. External Network for Switching Transducer

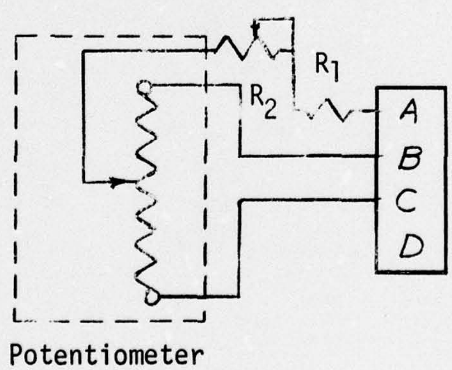


Figure 31. External Network for Potentiometer Transducer

Calibration Procedure

Calibrations of SR-4 type transducers were performed by the equivalent strain method. After the transducer was connected to a suitable monitoring device such as an Ellis Bridge Amplifier, the bridge was balanced. The transducer was then placed in a loading machine and subjected to its full rated load. The gain on the amplifier was then adjusted to obtain full scale deflection of the meter. After the load had been removed and the bridge balance rechecked, incremental loads were applied from zero to the rated load. Meter readings were recorded for each load. After the load was again removed, appropriate calibration resistors were switched into the circuit; meter readings were recorded for each resistance.

Since each of the above calibration resistor readings represents an equivalent load, calibration step readings could be superimposed on the load versus meter reading line to yield a load versus calibration-step line. The calibration step resistors in the bridge balance-calibration unit were matched to those in the Ellis Bridge Amplifier. Therefore, when a transducer was connected to the CSU recording system, equivalent loads could be simulated by switching in an appropriate calibration resistor. The gain was then adjusted to obtain proper deflection of the recording galvanometer.

An example of the steps necessary for recording an expected force of 200 to 300 pounds is as follows for a 1,000 pound transducer:

1. Balance the transducer bridge with no force applied.
2. Switch in an appropriate calibration step. From the load versus calibration step line for the 1,000 pound transducer Step 20 = 188 pounds.

3. Adjust the sensitivity potentiometer until the galvanometer trace deflects 1.88 inches with the calibration Step 20 switched into the bridge.
4. Switch the calibration step off and commence with the test. The sensitivity is now 100 pounds per inch deflection of the galvanometer trace.

SUMMARY

Vehicle mobility testing in a remote tropical environment presents some very special problems. Instrumentation systems must be reliable, simple, rugged, corrosion resistant, and have a small space requirement.

The Colorado State University Instrumentation Team designed and assembled an instrumentation system which performed exceptionally well under the above conditions. The problems outlined above were minimized by taking the following steps:

1. A d.c. recording system was used to eliminate the need for an engine driven a.c. power supply.
2. A Century light beam oscillograph was used; this proved to be an extremely rugged, lightweight, reliable unit.
3. A bridge balance-calibration unit was designed and fabricated which provided a very convenient method for providing power to transducers, attenuating the output signals from the transducers, balancing the bridge circuits, and for calibration of the transducers.
4. Lightweight force transducers were fabricated from high strength aluminum to minimize corrosion problems and excessive weight.

The recording system requires very little space and can be carried on the test vehicle. The system can be utilized to monitor drawbar pull, wheel slip, vehicle velocity, acceleration, vehicle yaw, vehicle roll, and vehicle pitch.